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A SIMPLIFIED FILM DOSIMETER FOR FISSION NEUTRONS

Research and Development Technical Report USNRDL-TR-224
NS 081-001

4 April 1958

by

S. W. Ross
E. Tochilin

U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORY

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Physics and
Mathematics

Technical Objective
AW-7

Nuclear Radiation Branch
C.S. Cook, Head

Nucleonics Division
A. Guthrie, Head

Scientific Director
P. C. Tompkins

Commanding Officer and Director
Captain J. H. McQuilkin, USN

U. S. NAVAL RADIOLOGICAL DEFENSE LABORATORY
San Francisco 24, California

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ABSTRACT

A film dosimeter technique has been developed for fast neutron monitoring of reactor personnel. The method takes advantage of the rapid build-up of thermal neutrons when fast neutrons are allowed to penetrate a hydrogenous moderator. The badge consists of a 3/4-inch thick polyethylene frontpiece that is worn on the belt against the body. A combination of silver and tin filters are matched so as to produce equal film blackening from either x- or gamma-rays. Fast neutron exposure is determined from film blackening under radioactive silver produced by capture of the moderated neutrons. The badge contains a sensitive gamma-ray dosimeter film together with a nuclear track emulsion. The dosimeter film serves as both a fast neutron and gamma-ray dosimeter. The nuclear emulsion is read whenever an overexposure is indicated or under any other conditions where a more accurate evaluation of the fast neutron dose is warranted.

SUMMARY

The Problem

The purpose of this investigation was to develop a neutron film dosimeter based on gross density measurements rather than on microscopic inspection of recoil proton tracks in nuclear emulsions.

The Findings

A combined neutron-gamma film badge dosimeter, containing tin and silver filters, was developed for monitoring of reactor personnel. Neutron film blackening in the polyethylene badge is produced by thermalization and subsequent capture of the incident neutrons to produce radioactive silver. A tolerance flux of fission neutrons will produce film blackening equivalent to a gamma-ray exposure of 40 mr. The film packet also contains a track plate emulsion which is read only if the dosimeter film indicates a fast neutron exposure or if film blackening from gamma-rays is great enough to mask any other readings.

ADMINISTRATIVE INFORMATION

Background of Work

During FY 1956 and FY 1957, the U. S. Naval Radiological Defense Laboratory prosecuted a Radiological Physics Program for the Bureau of Ships. The problem, Dosimetry for Neutrons, had as an objective, the investigation of new and improved methods of neutron dosimetry in connection with animal irradiation studies. From these measurements, it is possible to determine the variation of biological effectiveness with changes in neutron flux and energy.

Authorization and Funding

The Radiological Physics Program was sponsored by the Bureau of Ships, Technical Objective AW-7, Project Index NS 081-001, Effects of Atomic Warheads and Radiological Shielding, and was funded by allotment 30025/56 during FY 1956 and allotment 30005/57 during FY 1957.

Description of Work

The problem, "Dosimetry for Neutrons" is primarily an investigation of neutron dosimetry in connection with animal irradiation studies at the University of California 60-in. cyclotron. Of paramount concern was the determination of auto-integral gamma-ray dose in large animals irradiated with fission neutrons. A mathematical treatment has been developed for the determination of gamma-ray distribution in tissue for any neutron irradiation condition where the thermal component of neutron distribution can be established. This will lead to the development of a fast neutron film badge dosimeter, based on direct density measurements rather than nuclear track plate counting.

REPORT OF INVESTIGATION

INTRODUCTION

Fast neutron personnel monitoring is presently accomplished with dental type film packets containing nuclear emulsions. Recoil protons produced in the gelatin base of the emulsion traverse the silver halide grains which are registered as tracks and can then be counted by microscopic inspection to determine the degree of neutron exposure. The track plate technique was originally developed by Cheka who also pointed out the many problems associated with the method[1]. Subsequent refinements have been made to minimize some of these inherent shortcomings[2]. In spite of the fact that the nuclear emulsion technique remains a time consuming and tedious operation, it is still the most reliable method for routine monitoring of fast neutrons.

The primary neutron sources which are most important from the standpoint of personnel exposure are: (1) high energy particle accelerators which cover a wide range of neutron energies, and (2) experimental and power reactors where the neutron spectrum is restricted to fission neutrons.

The neutrons associated with accelerators are usually of high energy. Long tracks are produced in the nuclear emulsion, which in turn can be readily identified. On the other hand, proton tracks from fission neutrons are limited in range; many of the shorter tracks will traverse no more than 2 to 3 grains. Counting under such conditions becomes a much more difficult procedure. The sensitivity of track plate dosimetry is such that it is not possible to detect exposures less than one-half the weekly tolerance dose without introducing large statistical errors. Latent image fading in nuclear emulsion precludes any increase in effective sensitivity by wearing the films for periods of time longer than one or two weeks.

The rapid growth of the reactor industry and the relatively large number of people associated with its operation indicate that this field will soon constitute the most significant source of potential neutron exposure. For installations such as shipboard reactors, a simplified monitoring technique that would eliminate the need for a microscope is highly desirable. This is especially true aboard submarines where space and manpower requirements are critical.

For these reasons it was felt worthwhile to investigate the possibility of developing a simplified neutron film dosimeter designed specifically for reactor operation. This report describes the results of such a study.

FILM SENSITIVITY TO NEUTRONS

Survey of Earlier Work

Tochilin, Shumway, and Kohler have investigated the response of film to singly charged particles over a range of specific ionization extending from minimum to maximum values[3]. Measurements were made at the Berkeley 184-in. frequency-modulated cyclotron utilizing dosimetric techniques developed by Tobias, Anger, and Lawrence[4]. Three conventional dosimeter films and one nuclear emulsion were investigated. The dosimeter films were observed to behave in a manner illustrated by the lower curve of Fig. 1 plotted so that a dosage sensitivity of 1.0 is obtained at minimum specific ionization. It is seen that as particle energy is decreased, the dose required to produce a given density must be correspondingly increased to compensate for the loss in film sensitivity. In this respect, dosimeter films were found comparable to electron sensitive neutron emulsions where a continuous track is recorded even by electrons of minimum ionization. Thus, any particle that gives up more energy in a grain than is necessary to render it developable has in effect wasted this energy in so far as the process of photographic dosimetry is concerned. Film exposures to fission neutrons indicated that from 50 to 100 rad were required to produce the same density as one roentgen of Co^{60} gamma rays, depending on the type of film used.

Despite their low sensitivity to fast neutrons, films have been successfully used for monitoring thermal neutrons. A highly sensitive track plate technique using lithium and boron-loaded emulsions has been described by Titterton and Hall[5]. Kalil has developed a film badge capable of measuring combined exposures of thermal neutrons, beta, and gamma rays[6]. The badge is of conventional design consisting of an open window region together with brass and cadmium filters. A differential calibration between thermal neutrons and gamma radiation is made possible by thermal capture in cadmium followed by the emission of gamma ray photons.

Rausa has investigated the photographic effect of film exposed to fast and thermal neutrons in an aluminum film holder containing rhodium, cadmium, and lead filters[7]. Film blackening by rhodium results from beta decay of short-lived isotopes produced by thermal neutron capture. The thermal

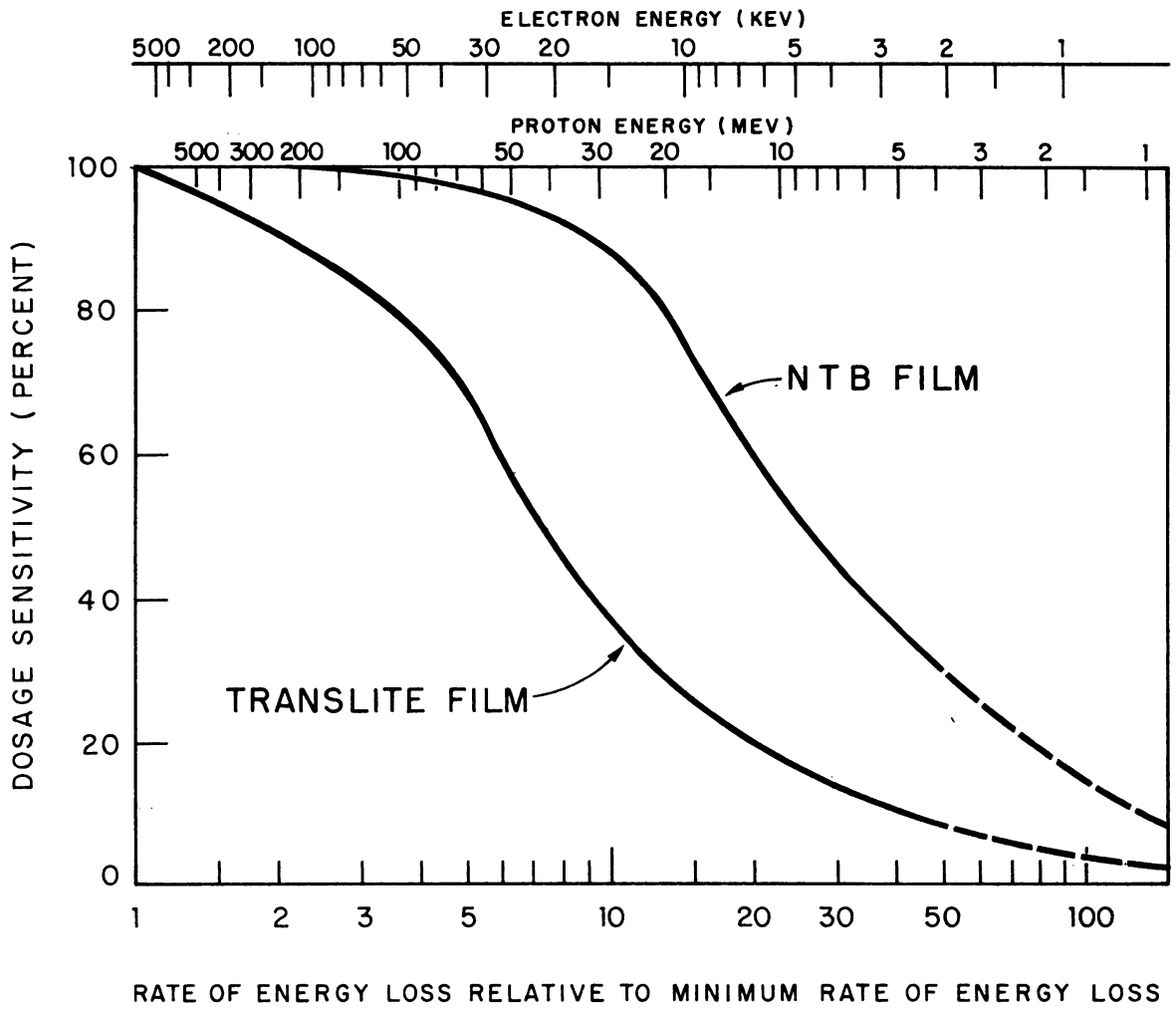
ELECTRON ENERGY (KEV)
500 200 100 50 30 20 10 5 3 2 1
PROTON ENERGY (MEV)
500 300 200 100 50 30 20 10 5 3 2 1
DOSAGE SENSITIVITY (PERCENT)
100
80
60
40
20
0
NTB FILM
TRANSLITE FILM
1 2 3 5 10 20 30 50 100
RATE OF ENERGY LOSS RELATIVE TO MINIMUM RATE OF ENERGY LOSS

Fig. 1 Sensitivity of Dosimeter Films to Electrons and Protons.

sensitivity using rhodium filters was such that 10^7 n/cm^2 produced blackening equivalent to 50 mr of Co^{60} gamma rays. This was some four times greater than the blackening obtained under Cd filters as a result of gamma emission.

The high sensitivity of film dosimeters to thermal neutrons suggests a thermalization technique as a method of photographically detecting fast neutrons. Fission neutrons, with a mean free path of 10 cm in water, are rapidly thermalized in hydrogenous material. The albedo for thermal neutrons in water is 0.8, thereby producing a high degree of reflectance from adjacent areas. Measurements in the core lattice of the Materials Testing Reactor consisting of fuel rods surrounded by water indicate that the fast neutron flux is only 30 to 40 percent of the thermal flux[8]. Thus with adequate moderation in hydrogen it is possible to produce a thermal neutron component comparable to the fast neutron flux.

The maximum permissible neutron flux at various neutron energies, for a 40-hour work week, is given in Table 1[9]. Assuming an average energy of 1 Mev and an exposure condition where the thermal neutron component is equivalent to the fast flux, a weekly tolerance dose of fission neutrons will produce 0.8 x 10^7 thermal neutrons/cm^2. From the data of Rausa on film sensitivity to thermal neutrons, this exposure will produce film blackening equivalent to 40 mr of gammas. The lower limit of film sensitivity for gamma-ray exposures is the order of 20 mr.

Experimental Studies

Initial work on the film badge dosimeter involved studies to determine: (1) the configuration and thickness of hydrogenous moderator for the badge, and (2) proper filter material to provide maximum thermal neutron sensitivity.

The experimental work was carried out with the following neutron facilities:

1. Fission-type neutrons from the University of California 60-in. cyclotron produced by 12 Mev protons and a thick Be target. The cyclotron provided a readily available source of neutrons where much background data on neutron dosimetry had previously been obtained[10].

2. Fission neutrons from the biological port of the Argonne CP-5 reactor produced by means of a uranium converter plate located in the thermal column. A 1/4-in. boral thermal neutron shield and a 4-in. bismuth shield were placed between the converter plate and exposure region[11].

3. Fission neutrons from the Los Alamos unreflected critical assembly "Godiva"[12]. The assembly consists of two 6-in. hemispheres of U^{235} and represents the minimum mass that will sustain fission.

TABLE 1

Maximum Permissible Neutron Flux for 40-Hour Week to Deliver 300 Millirems

Neutron Energy (Mev)	Maximum Permissible Flux	
	$n/cm^2/sec$	$n/cm^2/week$ $(x\ 10^{-7})$
Thermal	2000	29
0.005	1700	24
0.02	850	12
0.1	250	3.6
0.5	90	1.3
1.0	55	0.79
2.5	60	0.86
5.0	55	0.79
7.5	50	0.72
10.0	50	0.72
10 to 30	30(a)	0.43(a)

(a) Suggested limit.

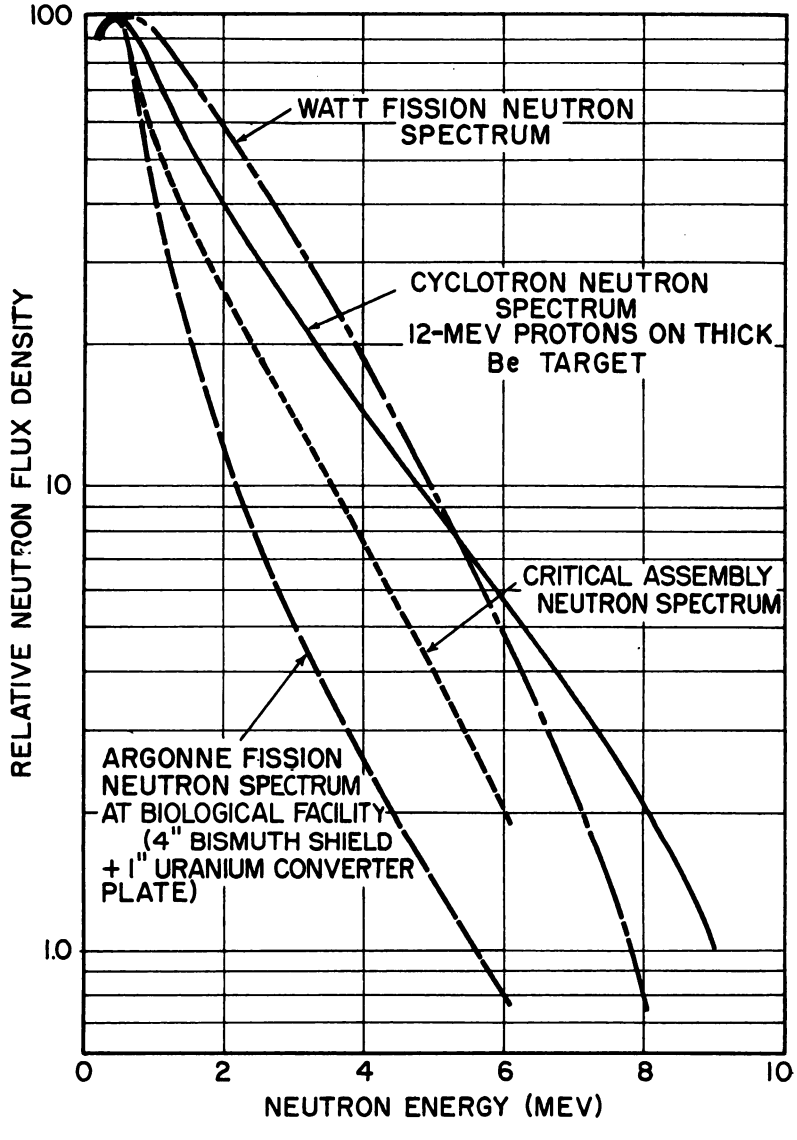

Fig. 2 Comparison of Various Fission Neutron Spectra.

4. Thermal neutrons from the thermal column of the water-moderated reactor (water boiler) at UCRL, Livermore.

Neutron spectra from the three fast neutron sources are given in Fig. 2, together with the primary fission neutrons as measured by Watt[13]. The Godiva spectrum was taken from the track plate data of Rosen, while the remaining spectra are the result of track plate measurements obtained at this Laboratory[10,14] Degradation of fission neutrons within Godiva results primarily from inelastic scattering within the U^{235} hemispheres. This leakage spectrum probably represents the maximum neutron energies to be expected from critical assemblies and reactors under conditions involving personnel exposures. The cyclotron neutrons give good approximation to the fission spectrum which, in turn, can vary widely depending upon the degree of moderation presented by reactor shielding material.

Foil measurements were made at the 60-in. cyclotron and at CP-5 to determine the degree of thermalization produced in hydrogenous material. Attenuation curves were obtained with gold and sulfur detectors in a water-filled plastic tank 12 in. on each edge. Figure 3 shows the gold curves obtained at CP-5 and the cyclotron. The thermal flux is seen to peak between 1 and 2 inches from the surface. Beyond this point the slope of the curve approximates that obtained for fast neutrons with sulfur threshold detectors[10]. Thermal neutron detectors such as gold exhibit strong resonances in the epithermal region. The epithermal component may be determined by exposing a second foil which is shielded from thermal neutrons by Cd. Also shown in Fig. 3 is the ratio of bare to Cd shielded gold foils exposed in the water tank at the cyclotron. The Cd ratio indicates that beyond a 2-in. depth over 90 percent of the bare foil activity is from the thermal component. Throughout the remainder of the report all reference to foil activity will include both the thermal and epithermal component.

Following an examination of elements with high thermal neutron absorption cross section, silver was chosen as the most suitable foil material for the proposed dosimeter. When activated by thermal neutron capture silver emits 1.7, 2.2, and 2.8 Mev betas with a maximum half-life of 2.3 min. The high energy beta rays can penetrate packets containing two films without appreciable attenuation while the half-life allows films to be developed within 15 min. after exposure without any loss in sensitivity.

The thermal neutron sensitivity of Eastman Type K and DuPont Type 555 films were determined by exposing films sandwiched between various thicknesses of silver in the thermal column of the Water Boiler. The gamma ray background was determined by covering another portion of the film with tin filters. Because of their proximity in atomic number, both tin and silver have similar gamma ray absorbing properties. At the same time tin is virtually transparent to thermal neutrons.

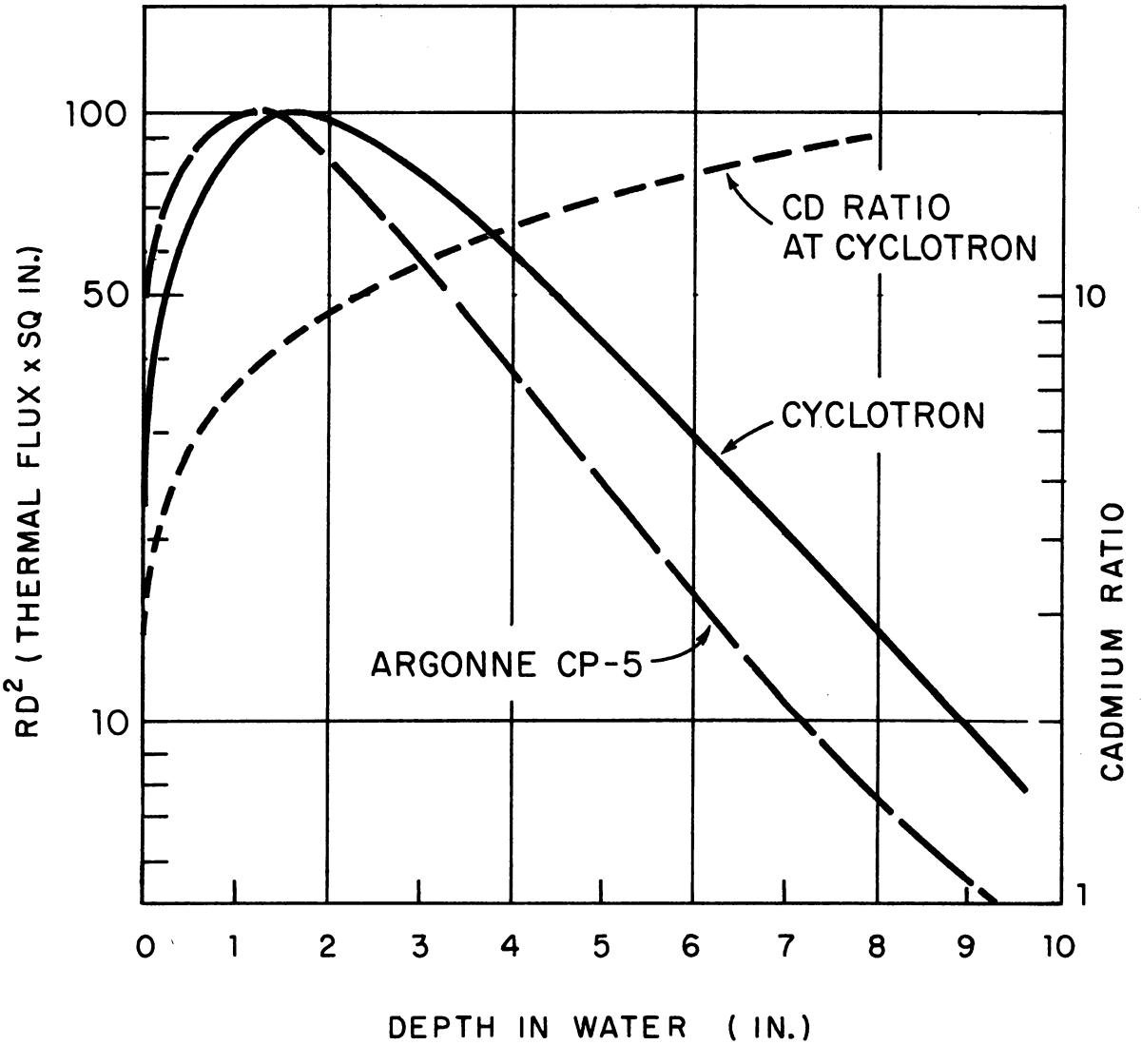

Fig. 3 Degree of Thermalization Produced by Hydrogenous Material as Measured by Gold Foil Detector.

Figure 4 shows the film sensitivity of DuPont 555 film as a function of foil thickness. At an optimum thickness of 0.014 in., a flux of 10^7 n/cm^2 will produce film blackening equivalent to 40 mr of Co^{60} gamma rays. An 18 percent decrease in film sensitivity was observed when films were exposed with the silver foils placed on the outside of the dental packets rather than in direct contact with the emulsion.

During the course of these exposures studies were also made of thermal neutron film sensitivity resulting from direct activation of the silver contained in the emulsion. Gamma-ray background was determined by making additional runs with films sandwiched between 1-in. thick Li disks in the manner suggested by Brennan, et. al.[15] A summary of the data for single and double coated Eastman Type K and DuPont Type 510 film is given in Table 2.

These studies were sufficient to establish that a badge could be designed to detect a weekly tolerance flux of fission neutrons. However, even for a badge restricted to fission neutrons, the question arises as to what constitutes a typical spectrum. It was already shown in Fig. 2 that various degrees of moderation are possible, extending from primary fission neutrons to highly moderated spectra approaching thermal energies. For this reason we have arbitrarily assumed a tolerance flux of 10^7 n/cm^2/week for the badge. This value is within 20 percent of the minimum value based on the data of Table 1 for a neutron energy of 1 Mev.

Some index of the energy dependence to be expected from changes in neutron spectrum may be obtained from studies made with other systems. One of these is a "long counter" which consists of a paraffin embedded BF_3 proportional counter with the counter located parallel to the beam axis. This arrangement provides an instrument which is nearly constant in sensitivity to a neutron flux of 0.1 to 3 Mev. The dosage sensitivity of such a detector (defined as the counts per unit dose) will increase with decreasing energy in approximately the proportions given in Table 1 for permissible tolerance flux.

DePangher and Roesch have studied the flux response and dosage sensitivity of a BF_3 counter surrounded by cylindrical shells of hydrogenous moderator in which case the detector was oriented perpendicular to the neutron beam[16]. For neutron energies of 0.16, 0.5, and 2.5 Mev the relative counts obtained per millirad were the order of 100, 60, and 10, respectively.

These results show that the dosage sensitivity of the proposed badge will rapidly increase with decreasing energies. Therefore, if the detector were calibrated at the highest fission neutron energies to be encountered film blackening obtained for all other conditions would give readings that were high and on the safe side.

The qualitative nature of the film dosimeter suggests that it be incorporated with a nuclear emulsion. With this combination the dosimeter film

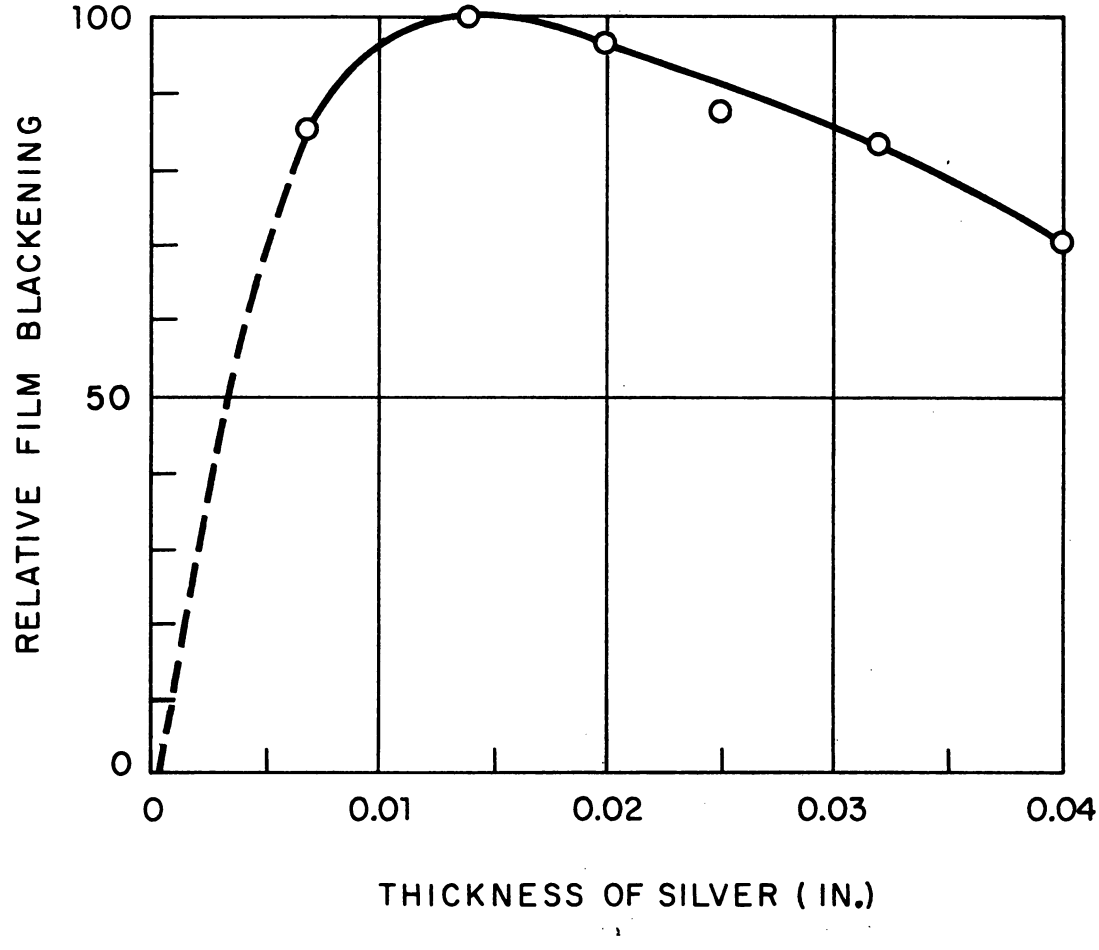

Fig. 4 Film Sensitivity as a Function of Foil Thickness (DuPont 555 Film).

TABLE 2

Film Sensitivity to Thermal Neutrons Due to Activation of Silver in Emulsion

Film	Emulsion Thickness (mg/cm^2)	Silver Thickness (mg/cm^2)	Equivalent Co^{60} Roentgens for $10^{10} n/cm^2$	
			Single Coated	Double Coated
Eastman Type K	6.2	1.9	0.57	0.90
DuPont Type 510	3.8	0.9	0.51	0.84

TABLE 3

Calibration of Fast Neutron Film Dosimeter

Neutron Source	Distance (cm)	Equivalent Co^{60} Roentgens for 10^7 n/cm^2
Critical Assembly (Godiva)	100	0.040
60-in. Cyclotron	107	0.037
Po-Be	35	0.029
	20	0.022
Pu-Be	10	0.010

would be used to determine gamma ray dose and would further serve as a monitor to establish the presence or absence of any significant fast neutron component. Track plate analysis would then be restricted only to those films where neutron exposure is indicated.

BADGE DESIGN AND CALIBRATION

The basic requirements for the proposed badge are:

1. Sufficient sensitivity to identify in a positive manner a weekly tolerance flux of fission neutrons.

2. A combination of two filters that will produce equal film blackening for any given x-or gamma-ray exposure. One filter will be activated by thermal neutrons to produce maximum film blackening while the other filter will be virtually transparent to this component.

3. Physical dimensions and weight to be kept within limits that will not be objectionable to the wearer.

Following several preliminary experiments, a badge was constructed as shown in Fig. 5. Polyethylene, which has the highest hydrogen content of all plastics, was chosen as the badge material. The front piece consists of a 3/4 in. polyethylene moderator 2-1/2 in. high and 2 in. wide, which is slotted to accommodate a dosimeter film pack. Restricting the front moderator to 3/4 in. resulted in about a 20 percent loss in sensitivity. However, this compromise was necessary in order to produce a reasonably small badge that was comfortable to wear. The 3/4 in. front and the 1/8 in. thick back piece are locked together by means of a spring type clip which also holds the badge on the belt. The badge is intended to be worn close to the body which acts as the additional thermalizing and back scatter material necessary to produce maximum thermalization. Both front and back pieces contain cavities for the two filters. The gamma ray filter is a tin shield 0.050 in. thick, while the neutron filter consists of 0.015 in. silver backed by 0.025 in. of tin to produce equal x- and gamma ray sensitivity for the two systems. These filters gave a flat x- and gamma ray response down to 100 kev. Film sensitivity decreased rapidly below this energy, falling to one-half at 60 kev and to zero at 35 kev. Low energy radiation can, however, be determined by the presence of excessive blackening in the unfiltered regions of the film packet. No provisions have been made to assess beta ray exposures.

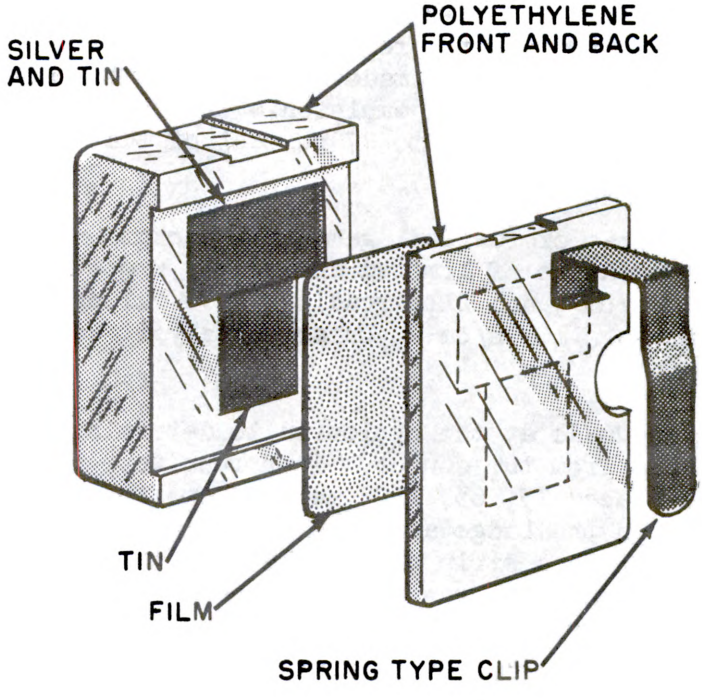

Fig. 5 Fast Neutron Film Badge.

All calibrations were made with the film badge placed directly in front of a 6 in. x 6 in. x 3 in. polyethylene block which simulated the body in serving as a moderator of fast neutrons. Calibration runs were made with Eastman Type K film at Godiva and at the 60 in. cyclotron. Two additional runs were made with Po-Be and Pu-Be neutron sources which were intended to serve as reference standards. The data are summarized in Table 3. For measurements made at a source-to-film distance greater than 100 cm, film blackening for a fast neutron flux of 10^7 n/cm^2 approximated a 40 mr Co^{60} exposure. The decrease in sensitivity observed at closer distances with the reference standards will be discussed later. Cyclotron exposures were also made with an Eastman packet containing both Type K dosimeter film and NTA nuclear emulsion. The shielding provided by the NTA emulsion reduced sensitivity to 77 percent of that obtained with the K film alone.

Due to the high degree of residual gamma ray background associated with the Godiva source the data are of limited accuracy. Exposures extended from 2.7×10^7 to 1.6×10^9 n/cm^2, and film readings gave values scattered over a range from 23 to 60 mr per 10^7 n/cm^2. Unfortunately it was not possible to repeat these measurements.

Exposures were also made at the cyclotron to determine how film sensitivity would vary with distance from the source. Four runs were made with the badge and backscatter block placed 25, 63, 110, and 170 cm from the target. Depth dose curves were taken through the badge and moderator block by slicing the assembly in half and placing a strip of film between the two pieces. The film, located parallel to the beam axis, was in turn sandwiched between adjoining strips of silver and tin. The resultant component of film blackening due to activation of the silver foil is plotted in Fig. 6. The top curve, obtained with a larger moderator, will be discussed later. Identical curves were obtained for the two exposures made at distances greater than 100 cm. At the closer distances film sensitivity decreases and becomes strongly dependent upon geometry. The curves also show that the peak value of thermal response produced in the moderator is of the order of 25 percent greater than that recorded in the film badge. The relative film response of the badge per unit flux was 0.51, 0.81, 1.0, and 1.0 at the four distances listed above.

Referring back to Table 3, the film response at 20 cm with the Po-Be source is approximately half the value obtained with the Godiva and cyclotron neutrons. The data in Fig. 6 further indicates that a similar loss in film sensitivity would be expected with the fission type spectra for exposures made at this distance. On this basis one would expect the badge to have essentially the same sensitivity for Po-Be or Pu-Be neutrons (with average neutron energies of 4.5 Mev) as for fission neutrons. The calculated depth dose data of Snyder and Neufeld for broad beams of fast neutrons in tissue show that, for a given fast flux, the peak value of thermal neutron flux in the moderator will not differ by more than 30 percent for neutron energies between 0.5 to 5.0 Mev[17]. These calculations indicate that a fast neutron dosimeter based on a measure of this

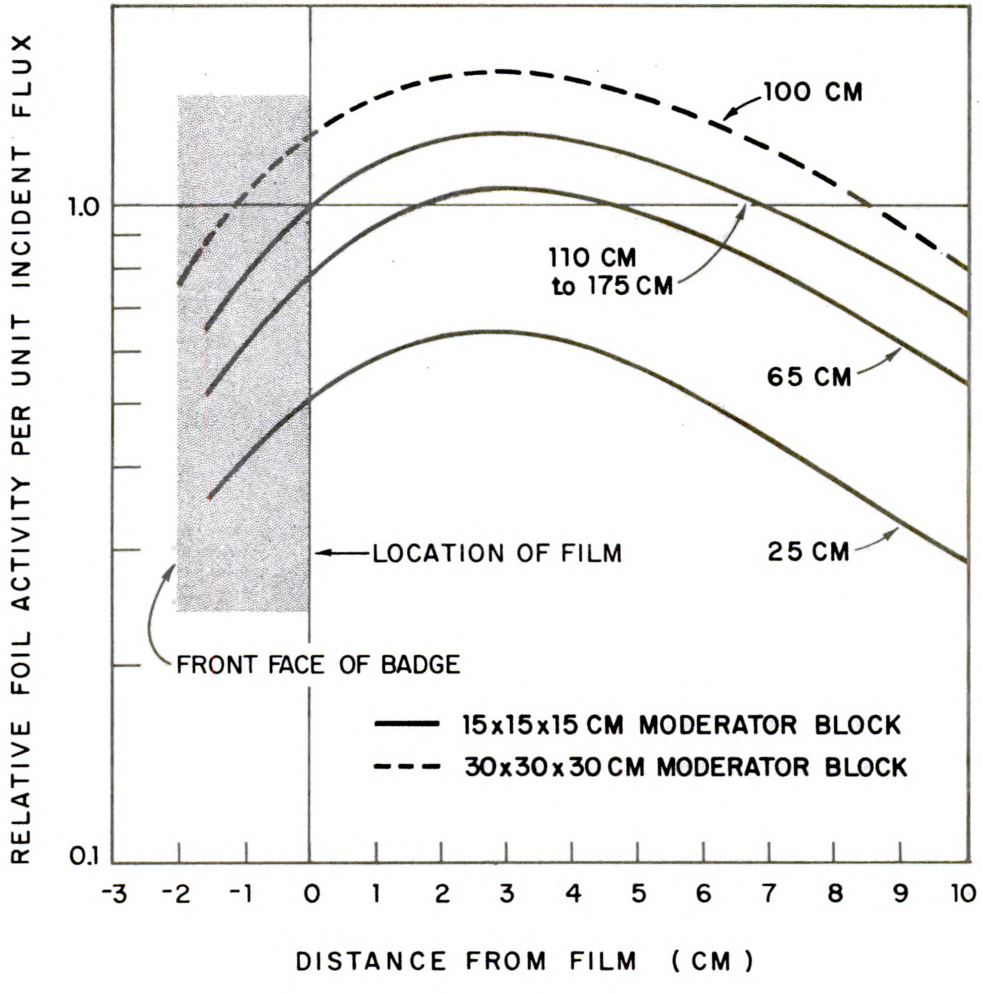

Fig. 6 Exposures Made at the 60-inch Cyclotron to Determine How Film Sensitivity (film blackening of silver foil) Varied with Distance from the Source.

TABLE 4

Film Sensitivity of Neutron Badge Removed from Hydrogenous Moderator

Distance from Hydrogenous Backing (in)	Relative Film Sensitivity
0	100
1/8	96
1/4	87
1/2	82
3/4	74
1	74

peak thermal component would be reasonably independent of neutron energy over wide limits. A more complete investigation of this relationship is in progress.

In order to determine the influence of moderator block on film sensitivity, a series of exposures was made with the badge removed from intimate contact with the moderator. Table 4 lists the measured decrease in sensitivity with the badge placed at increasingly greater distances from the source. For a separation of 1 in., film sensitivity had decreased to 74 percent of its maximum value.

In another series of runs moderator blocks of different sizes were used. The top curve of Fig. 6 shows the increase in film sensitivity obtained with a polyethylene block 12 in. on each side. It is not expected that any significant increase beyond this point will be obtained. Other comparisons were made with moderators smaller in size than the standard units. A block 1 in. thick and the same size as the badge, reduced the sensitivity to 47 percent. A 1 in. rather than a 3 in. thick block of standard moderator reduced the sensitivity to 73 percent of the value originally obtained. Exposures made in a lucite badge showed a 10 percent decrease in sensitivity over that obtained with the polyethylene dosimeter. A corresponding increase in sensitivity could be obtained by use of high density polyethylene and special molding techniques.[18]

Film badge sensitivity will also be influenced by the presence of any therma neutron component which may accompany the fast neutron flux. The degree to which thermal neutrons will affect the badge may be estimated from the data of E. Stickey who has measured the penetration of slow neutrons in tissue[19]. An attenuation no greater than a factor of two would be expected from the polyethylene front piece.

SUMMARY

A film badge is described which serves both as a gamma ray and fast neutron dosimeter. Film blackening results from thermalization of fast neutrons in the polyethylene badge and their subsequent capture by silver filters contained in the unit. The film badge is worn against the body which serves as an additional moderator of fast neutrons. Following the prescribed wearing period both films (dosimeter film and nuclear emulsion) contained in the packet are processed. Density measurements are taken under the film areas corresponding to the tin and silver filter to determine the degree of gamma ray and fast neutron exposure. The track plate is read only if the film dosimeter indicates a fast neutron exposure or if film blackening from gamma rays is great enough to mask any possible neutron exposure.

The badge is calibrated with fission neutrons or with a suitable reference neutron standard such as a Po-Be source. A tolerance flux of primary fission neutrons will produce film blackening equivalent to 40 mr of Co^{60} gamma rays. Film sensitivity will increase for a degraded fission spectrum.

Approved by:

A. GUTHRIE, Head
Nucleonics Division

For the Scientific Director

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39	CO, Naval Unit, Army Chemical Center
40	CO, U. S. Naval Civil Engineering (Res. and Eval. Lab.)
41	Commander, Naval Air Material Center, Philadelphia
42	CO, Naval Schools Command, Treasure Island
43	CO, Naval Damage Control Training Center, Philadelphia
44	U. S. Naval Postgraduate School, Monterey
45	CO, Fleet Training Center, Norfolk
46-47	CO, Fleet Training Center, San Diego
48	Commander, Naval Ordnance Laboratory, Silver Spring
49	Naval Training Devices Center, Port Washington
50	Office of Patent Counsel, Mare Island
51	Commander Air Force, Atlantic Fleet (Code 16F)
52	Commandant, U. S. Marine Corps
53	Commandant, Marine Corps Schools, Quantico (Library)
54	Commandant, Marine Corps Schools, Quantico (Development Center)

ARMY

55-56	Chief of Research and Development (Atomic Division)
57-58	Assistant Chief of Staff, G-2
59	Chief of Engineers (ENGEB, Dhein)
60	Chief of Engineers (ENGNB)
61	Chief of Transportation (TC Technical Committee)
62	Chief of Ordnance (ORDTN-RE)

63	Ballistic Research Laboratories
64	The Quartermaster General
65	CG, Chemical Corps Res. and Dev. Command
66	Hq., Chemical Corps Materiel Command
67	President, Chemical Corps Board
68	CO, Chemical Corps Training Command (Library)
69-70	CO, Chemical Warfare Laboratories
71-73	CG, Aberdeen Proving Ground (Library)
74	Office of Chief Signal Officer (SIGRD-8B)
75	Walter Reed Army Medical Center
76	CG, Continental Army Command, Fort Monroe (ATDEV-1)
77	CG, Quartermaster Res. and Eng. Command
78	Director, Operations Research Office (Librarian)
79	CO, Dugway Proving Ground
80-82	The Surgeon General (MEDNE)
83	Office of Quartermaster General (R&D Div.)
84	Director, Evans Signal Laboratory (Nucleonics Section)
85	CG, Engineer Res. and Dev. Laboratory (Library)
86	CO, Transportation Res. and Dev. Command, Fort Eustis
87	NLO, CONARC, Fort Monroe
88	Director, Office of Special Weapons Development, Fort Bliss
89	CO, Ordnance Materials Research Office, Watertown
90	CO, Watertown Arsenal
91	CO, Frankford Arsenal
92	Signal Corps Center, Fort Monmouth
93	Tokyo Army Hospital

AIR FORCE

94	Directorate of Intelligence (AFOIN-3B)
95	Commander, Air Materiel Command (MCMTM)
96	Commander, Wright Air Development Center (WCRTY)
97	Commander, Wright Air Development Center (WCRTH-1)
98-103	Commander, Wright Air Development Center (WCACT)
104	Commander, Air Res. and Dev. Command (RDTW)
105	Directorate of Installations (AFOIE-ES)
106-107	Commandant, School of Aviation Medicine, Randolph AFB
108	CG, Strategic Air Command (Operations Analysis Office)
109	Commander, Special Weapons Center, Kirtland Air Force Base
110	Director, Air University Library, Maxwell Air Force Base
111-112	Commander, Technical Training Wing, 3415th TTG
113	CG, Cambridge Research Center (CRZT)

OTHER DOD ACTIVITIES

114	Chief, Armed Forces Special Weapons Project
115	Commander, FC/AFSWP, Sandia (FCTG (Library))
116	Commander, FC/AFSWP, Sandia (FCDV)
117	OIC, Livermore Branch, FC/AFSWP

118	Assistant Secretary of Defense (Res. and Dev.)
119-123	Armed Services Technical Information Agency

AEC ACTIVITIES AND OTHERS

124-125	Federal Civil Defense Administration
126	Alco Products, Inc.
127	Argonne Cancer Research Hospital
128-137	Argonne National Laboratory
138	Atomic Bomb Casualty Commission
139-141	Atomic Energy Commission, Washington
142-143	Atomics International
144-147	Babcock & Wilcox Company
148-149	Battelle Memorial Institute
150-153	Bettis Plant
154	Boeing Airplane Company
155-158	Brookhaven National Laboratory
159	Brush Beryllium Company
160	Carnegie Institute of Technology
161	Chicago Patent Group
162	Columbia University (Hassialis)
163	Columbia University (Havens)
164	Combustion Engineering, Inc.
165-166	Consolidated Vultee Aircraft Corporation
167	Convair-General Dynamics Corporation
168	Defense Research Member
169	Department of Food Technology, MIT
170	Dow Chemical Company, Pittsburg
171	Dow Chemical Company, Rocky Flats
172-174	duPont Company, Aiken
175	duPont Company, Wilmington
176-177	General Electric Company (ANPP)
178-189	General Electric Company, Richland
190	General Nuclear Engineering Corporation
191-192	Goodyear Atomic Corporation
193-194	Iowa State College
195-197	Knolls Atomic Power Laboratory
198-199	Lockheed Aircraft Corporation, Marietta
200-201	Los Alamos Scientific Laboratory
202	Mound Laboratory
203	National Advisory Committee for Aeronautics
204	National Bureau of Standards (Library)
205-206	National Bureau of Standards (Taylor)
207	National Lead Company, Inc., Winchester
208	National Lead Company of Ohio
209	New Brunswick Laboratory
210-211	New York Operations Office
212	New York University
213-214	Nuclear Development Corporation of America

215	Nuclear Metals, Inc.
216	Oak Ridge Institute of Nuclear Studies
217-222	Oak Ridge National Laboratory
223	Patent Branch, Washington
224	Pennsylvania State University (Blanchard)
225-228	Phillips Petroleum Company
229	Princeton University (White)
230-231	Public Health Service, Washington
232	RAND Corporation
233	Sandia Corporation
234	Sylvania Electric Products, Inc.
235	Technical Research Group
236	Tennessee Valley Authority
237	The Martin Company
238	Union Carbide Nuclear Company (C-31 Plant)
239-240	Union Carbide Nuclear Company (ORGDP)
241-243	United Aircraft Corporation
244	U. S. Geological Survey, Denver
245	U. S. Geological Survey, Menlo Park
246	U. S. Geological Survey, Naval Gun Factory
247	U. S. Geological Survey, Washington
248	U. S. Patent Office
249	UCLA Medical Research Laboratory
250	University of California Medical Center
251-252	University of California Radiation Laboratory, Berkeley
253-256	University of California Radiation Laboratory, Livermore
257	University of Rochester (Technical Report Unit)
258-259	University of Rochester (Marshak)
260-261	University of Washington (Geballe)
262	Vitro Engineering Division
263	Weil, Dr. George L.
264-265	Westinghouse Electric Corporation
266	Yale University (Breit)
267	Yale University (Schultz)
268-292	Technical Information Extension, Oak Ridge
	USNRDL
293-320	USNRDL, Technical Information Division

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